DEMONSTRATING NEW ATM-CONCEPTS IN A NEW LOW COST SIMULATION ENVIRONMENT

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Introduction

The exact definition of the relevant abilities of successful job candidates is the basis for a fair and valid personnel recruitment system. However, when an operational context is about to undergo fundamental changes concerning task demands in the near future, the predictive validity of the recruitment methods used today may be questioned. One of the fundamental principles of classic recruitment, that work demands should correspond to the stable patterns of individual interests and talents, is then challenged. According to international expert associations (e.g., SESAR Consortium, 2008; JPDO, 2007) the air traffic management (ATM) system will undergo fundamental changes within the next fifteen years. There is a high pressure to increase transport capacities by the factor two or three (ACARE, 2004; Krois, McCloy, & Piccone, 2007), while meeting, at least, today's safety standards. This immense future increase in air traffic cannot be managed without introducing new technologies and operational concepts, which in turn defines new responsibilities, roles and tasks for all actors in the ATM-system. Future job functions could be more flexible, interchangeable and proactive than today (Hoermann, Schulze Kissing, Zierke, & Eißfeldt, 2009).

The European master plan for future ATM (SESAR Consortium, 2008) is committed to operational concepts comprising airborne self separation by using airborne separation assistance systems (ASAS). Free flight requires airborne self-separation and its monitoring on the ground. Functionally, ASAS is the main technical prerequisite to implement free flight, for which CDTI (cockpit display of traffic information) is one example. The future growth in air traffic is an issue for which free flight is intended to offer solutions. Free flight is defined as "a safe and efficient flight operating capability under instrument flight rules in which the operators have the freedom to select their path and speed in real time" (RTCA, 1995). A considerable number of studies have already been carried out which look at specific effects, e.g., in terms of workload and situation awareness (Endsley, Mogford, & Stein, 1997), conflicts (Hilburn, Bakker, & Pekela, 1997) or the increased risk of collisions (Hoekstra, Ruigrok, & van Gent, 2000). As Hollnagel (2007) puts it, "*A transition from managed flight to free flight will change the working conditions for air-traffic controllers as well as for pilots. Since the two groups can be considered both as individual and as part in a larger JCS* [joint cognitive system]*, it is necessary to understand how the change to free flight may change system boundaries as well as system interactions*" (p. 415). The authors pick up the point of criticism that first it must be ascertained whether the nature of work remains the same as before. "*What we need to study is not different work under the same conditions, but rather different work under different conditions*" (Hollnagel, 2007, p. 416). The main conclusion Hollnagel (2007) has drawn is that the two conditions of managed and free flight differ considerably regarding the demands to control and hence regarding the tasks required. How can the new tasks be described, and is there a consequence for ability-requirement testing in recruitment of the future air traffic control and cockpit workforce?

Goals of the study. A first experiment is reported of a series of studies planned aiming to prospectively analyse the nature of future work for air-traffic controllers and pilots in the coming ATM system and to identify the ability requirements for future recruitment. The current experiment is intended as an exploratory analysis, to gain familiarity with the assessment of differences in work conditions by introducing new operational principles, like airborne separation. At the same time it provides a first validation of the experimental setup.

Method

A mixed approach is used. Before rating the task requirements on a job analysis scale, experts of both domains (air traffic control officers and airline pilots) jointly worked on future scenarios (free flight and managed flight) that are presented on a simulation platform. It is assumed that the previous experience of standardized scenarios increases the reliability and validity of the expert ratings compared to a mere questioning, where general attitudes towards certain concepts could have a stronger effect on the outcome.

Participants

Twenty male operators participated in the study, five of whom are centre controllers of the Deutsche Flugsicherung (DFS) with an average of 30 years work experience and 15 licensed Lufthansa pilots with an average experience of 1394 flight hours. The mean age of operators is 31.9 years.

Material

Simulator. The simulation platform is designed to meet the requirements of highest realism with lowest cost, high adaptability, and controllability for experimental purposes. With an open LAN architecture the simulation platform AviaSim (Hoermann et al., 2009) is currently configured for one controller position and up to eight cockpit positions for pilots. However, one air traffic control and three cockpit positions are used for the actual simulation study. The workstations are PC based and equipped with the necessary peripherals for task performance. The air traffic control environment, which is based on the off-the-shelf simulator *London Control*©, provides a short-term conflict alert (STCA) function, various flight-plan visualisations, and interactive labels for data-link communication. The cockpit environment is based on the *Microsoft Flight Simulator*© containing an integrated traffic-visualization system (Cockpit Display of Traffic Information, CDTI). The CDTI also provides an STCA function. The symbology used for the CDTI is based on the specifications made by Johnson et al. (1997), (For a more detailed description see Hoermann, Schulze Kissing, & Zierke, 2009.) A transparent field is projected into the cockpit window on which ATC instructions transmitted via data-link are displayed (see Figure 1). Controllers are instructed to communicate solely via data link, and pilots are instructed to expect data link instructions from ATC. As the simulated cockpits do not provide a data link input device, pilots have to use the voice channel to read-back ATC-instructions and for aircraft-to-aircraft communication under free flight. Thus, all workstations are provided with headsets for voice communication.

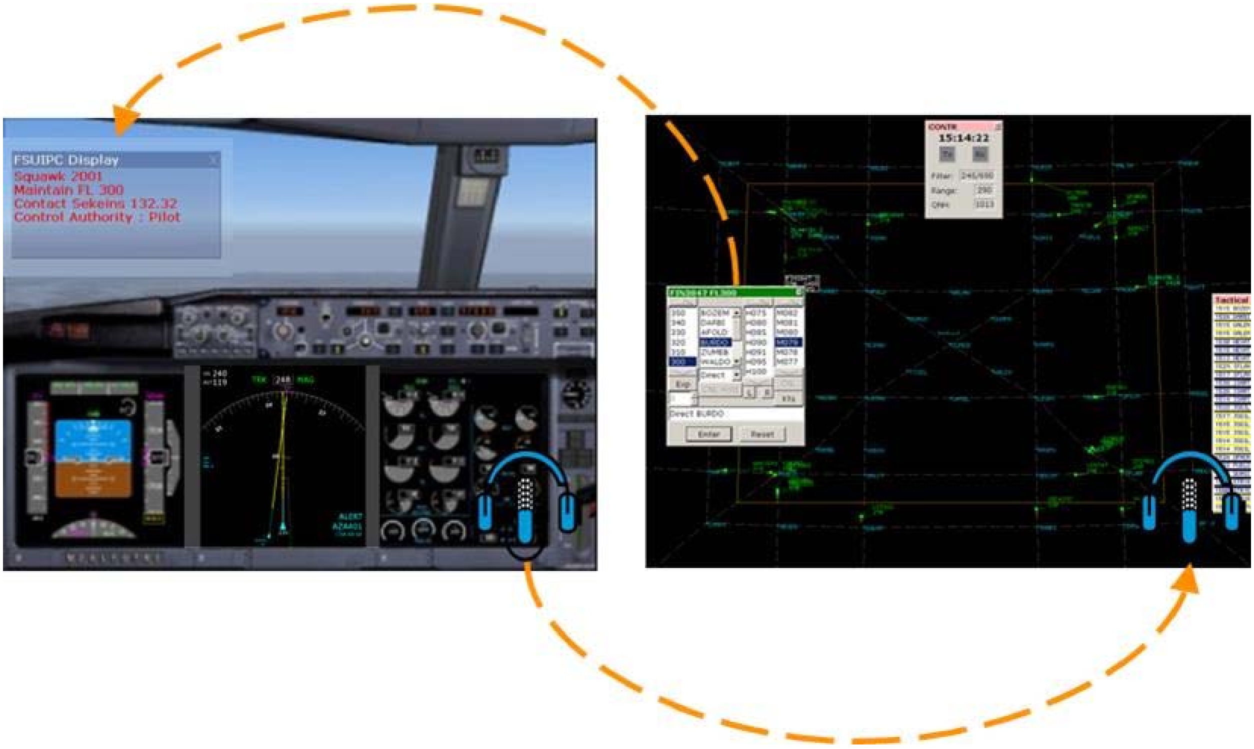

Figure 1: Screenshots of the Flight-Simulator (left) and ATC workstations (right; both with overlayed head-set symbols) provided by AviaSim; the arrows indicate the information flow from ground to cockpit via datalink, and from cockpit to ground via voice communication; the CDTI is displayed in the centre of the flight simulator display.

Airspace structure. The control sector has a rectangular shape with a diagonal of 240 NM, and level bands from FL 240 to FL 400. The fix-posts are scattered symmetrically across the sector. Fix-posts and sector boundaries are identical for both conditions. For the managed flight condition, fix-posts are connected by routes. However, for the free-flight condition the airspace is created by using the identical sector structure, with a rectangular zone inserted into the sector centre of about 80 NM in diagonal, containing no route structures (see Figure 2). At each corner of this zone there is a triangular shape representing sub-zones for transition into or out of free-flight, respectively. The concept of transition zones as well as the system of rules for aircraft transitions from managed airspace (MAS) to free flight airspace (FFAS) are adopted from Beers and Huismann (2002) and Ruigrok, de Gelder, and Scholte (2005).

Traffic samples. The traffic sample per scenario trial comprises 24 aircraft. Twenty-one aircraft are driven by the air traffic control component of AviaSim (further referred to as 'synthetic aircraft'), and three aircraft are piloted via Microsoft Flight Simulator instances. When traversing the transition zone, operators have to cope with situations of mutual merging and spacing. Additionally, self separation is required when operators encounter crossing traffic at the central route-intersection (see also Figure). The traffic for the two experimental conditions (managed flight without CDTI and free flight with CDTI) is made comparable by changing call-signs and the geometric relations without changing the spatio-temporal relations between the aircraft.

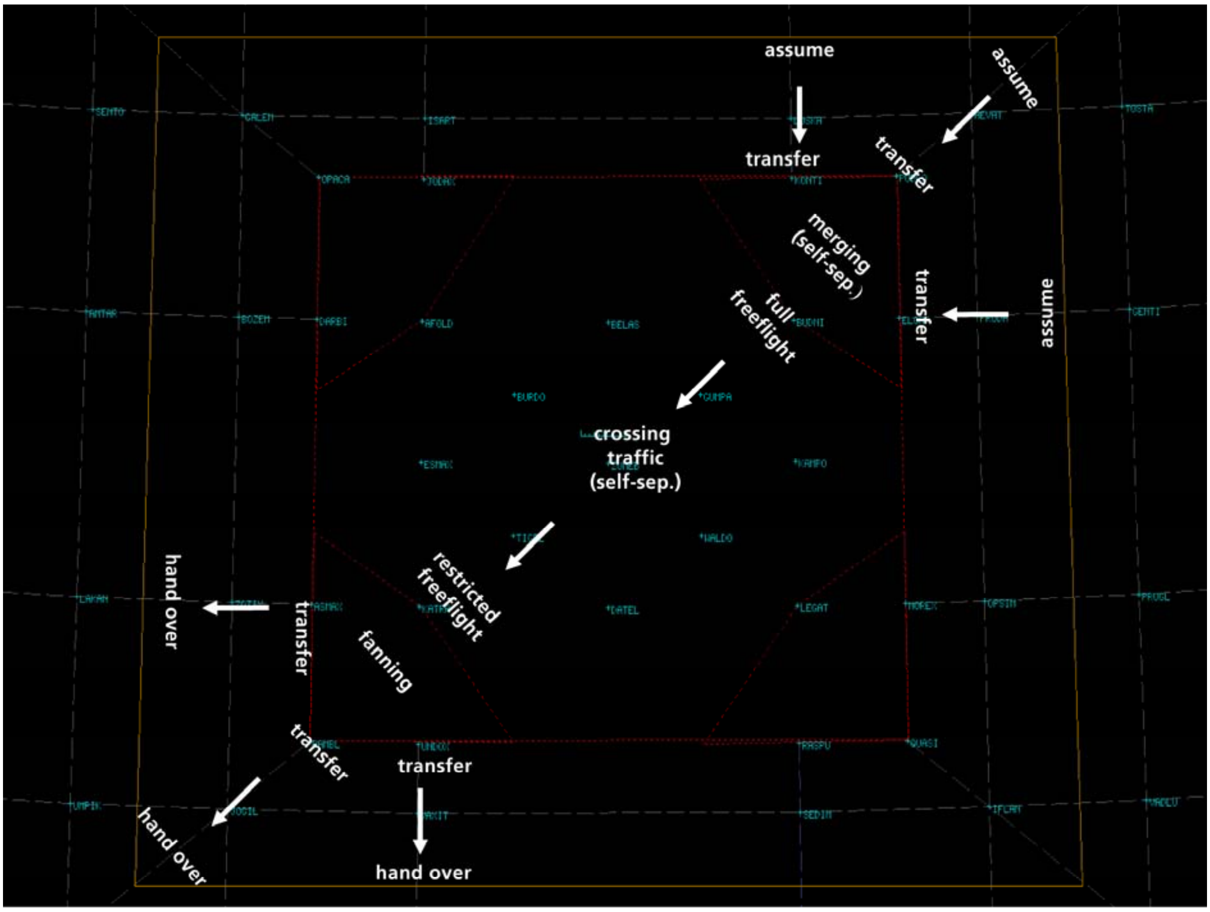

Figure 2: Screenshot of airspace structure, with sector boundaries defined by the yellow lines, and the free-flight airspace within indicated by the dotted read lines; arrows and comments are overlayed to indicate the evolvement of traffic situations for the 3 piloted aircraft during a scenario trial.

Experimental Plan

A one-factorial complete repeated measures design is used. The independent variable is the control authority for the flights within the sector, with the two levels '*MAS – CDTI inactive*' (one run per trial) and '*FFAS – CDTI active*' (two runs per trial).

Measurements

Differences in work and working conditions between managed and free flight for controllers and pilots are assessed by using the Fleishman Job Analysis Survey (F-JAS; Fleishman, 1992). Workload is measured by using *NASA Task Load Index* (NASA TLX; Hart & Staveland, 1988), and situation awareness with the *Situation Awareness Rating Technique* (SART; Taylor, 1990). All these measurements are taken at the end of each of the three simulation runs. To assess the gradient of workload and situation awareness in a simulation run, two according scales for instantaneous self assessment (ISA) are administered for immediate assessment during simulator freezes. Simulation log files are analysed for the numbers and points in time of controllers' actions for aircraft separation. System-safety (or system performance) is measured by the total number of losses of separation, as well as by the total number of STCAs.

Experimental runs

Advance information material is sent to brief the operators about the aims of the experiment, the simulation system, and the task setting. The simulation experiment is conducted at the human-factors laboratory at DLR Hamburg.. Five groups of one controller and three pilots are observed. There are two days of examination for each group. The first day starts with a one-hour briefing with a comprehensive rehearsal of the advance information. The operators then are seated in separate rooms for the subsequent simulation trials. The first day ends with a one-hour joint scenario training run and a debriefing to give room for open questions. The second day starts with a repetition of the concept of transition-zones and the system of rules for transitions from MAS to FFAS and vice versa. Then three en-route scenarios of about 45 minutes duration are exercised jointly. One scenario with the traffic managed entirely by ATC (managed flight condition without CDTI), and two scenarios with an airspace containing a free flight zone (free flight zone condition with CDTI) are presented. In the latter, pilots have the freedom to select their path and speed in real-time. The two free-flight scenarios are identical. However, between the runs pilots swapped the flight plans and the call-signs, so they experienced different airspace situations. The sequence of scenario presentation is changed between the groups.

At the beginning of each scenario the piloted aircraft as well as the synthetic aircraft are positioned airborne outside the sector boundaries. In the course of the flights the sector is filling up with 24 aircraft heading from four different directions (northeast, northwest, southeast and southwest). Shortly after the three piloted aircraft are on the controllers' frequency, the simulation is frozen for a first *ISA* rating. The next freeze is triggered during the merging situation between the three piloted aircraft at one of the four three line crossings. In a free flight run this situation is emerging within the transition zone. The third freeze for instantaneous measurement of workload and situation awareness is made when piloted aircraft encounter crossing traffic at the sector centre. Every scenario ends with the hand over of piloted aircraft to the neighbouring sectors. Subsequently the operators filled out the NASA TLX, SART and F-JAS questionnaires. After completing the last simulation run, an additional questionnaire is handed out to assess acceptability of both, simulation environment as well as scenarios used. The second day ends with a debriefing session of about one hour duration, where the operators can finally express their experiences, ideas and points of criticisms.

Hypotheses

It is assumed that future job functions are more interchangeable than today. A convergence of pilots and air traffic controllers' expert ratings of job requirements for the free flight condition compared to the managed flight condition should be observable. It is also assumed that the experimental setup is sensitive to effects of free flight on pilots' and controllers' workload and situation awareness (e.g., Endsley et al., 1997; Hilburn et al., 1997; Hoekstra et al., 2000). A replication of effects can be interpreted as a first indication that the simulation environment is also a usable platform for future operational concept validations.

Results

First, results on performance and self assessment data on workload and situation awareness are reported. Especially performance data provide an objective view of how work for ATCOs and pilots may change by the introduction of self separation procedures. Subsequently the respective expert ratings on changing job requirement are presented.

Validation of Experimental Setup

Controller performance. As expected, there is a significant overall difference between the experimental conditions concerning the number of flight level clearances made by the controller to the three pilots [χ^2 (2, N = 100) = 7.58; $p < .10$]. In the first run of the free-flight scenario controllers give less instructions for traffic separation (n= 21) compared to the managed flight (status quo) condition (n= 43). However, in the second run the controllers increase the number of instructions for traffic separation (n= 36), so that when measurement is repeated the effect between the free flight condition and the managed flight condition on the frequency of traffic separation instructions can no longer be observed. The first separation instructions after scenario start are given earlier in time in the second simulation run of the future scenario (M= 11.86 min., SD= 6.49) than in the first run (*M*= 19.90 min., *SD*= 12.51). A test of within-subject contrasts revealed a marginal effect [$F(1, 11) = 3.33$, $p < .10$] of the repeated measure on the time controllers made their first separation instructions of small size ($\varepsilon^2 = .25$). According to their own statements the controllers are unaware that the same traffic sample has been used for the second as for the first free-flight scenario. In total, 67 % of the separation instructions are flight level instructions, 30 % direct routings and just 3 % heading instructions. A chi-square test of differences in frequency of separation instructions per aircraft yielded no significance.

Table 1: Situation Awareness Rating Scores (Standard errors in brackets)

Independent variables		SART	ISA (situation awareness; range: 1-3) Merging	Crossing	Fanning
MAS	ATCOs	47.8 (15.6)	1.6 (.2)	1.2 (.2)	2.0 (.0)
	Pilots	92.4 (7.9)	2.9 (.1)	2.9 (.1)	2.7 (.2)
FFAS 1st Run	ATCOs	62.5 (16.1)	2.0 (.3)	2.4 (.4)	2.2 (.2)
	Pilots	95.6 (6.9)	2.9 (.1)	2.7 (.1)	2.7 (.1)
FFAS 2nd Run	ATCOs	68.9 (24.0)	2.4 (.4)	2.8 (.2)	2.4 (.2)
	Pilots	80.1 (7.2)	2.7 (.1)	2.5 (.1)	2.4 (.2)

Note: header "Dependent variables" spans SART and ISA columns.

Safety produced by the joint cognitive system (JCS). In the experimental trials a total number of $N = 15$ losses of separation, $N = 15$ separation regains, and $N= 56$ STCA are measured. System safety significantly differs between the three experimental conditions [χ^2 (2, $N = 86$) = 12.86; $p < .10$]. This is indicated by a significant difference in the number of STCA [χ^2 (2, $N = 56$) = 6.46; $p < .10$], as well as by a trend to different frequencies of losses of separation [χ^2 (2, $N = 15$) = 4.80; $p < .10$]. Compared to the managed flight condition there is a trend for more frequent losses of separation ($n= 9$) in the first free-flight scenario [χ^2 (1, $N = 12$) = 3.00; $p < .10$], as well as a significantly lower number of STCA ($n= 10$) under the second run of the free flight condition [χ^2 (1, $N = 31$) = 3.90; $p < .10$]. The number of losses of separation in the free-flight scenario as a trend decreases from the first ($n= 9$) to the second run ($n= 3$) [χ^2 (1, $N = 12$) = 3.00; $p < .10$].

Situation awareness and workload. SART (10 dimensional version) values do not indicate that controllers have different situation awareness under managed flight and free flight conditions. Pilots' SART data on the other hand suggest an overall difference in situation awareness depending on the conditions [Test of within-subject effects: $F(1, 14) = 2.67$; $p < .10$; $\varepsilon^2 = .16$]. On a descriptive level this marginal effect may be attributed to a decline of Situation Awareness (SA) in the second run of the free-flight scenario (compare Table 1). Single comparisons between pilots' SA values, however, yielded no significance. Analysing the subscales separately, data show that with introducing free flight no changes are to be expected regarding the situational understanding. But there is a trend indicating that with introducing free flight controllers tend to invest less attention resources for task performance [$F(2, 3) = 7.18$; $p < .10$; $\varepsilon^2 = .83$]. A single comparison revealed significantly lower scores on the accordant SART subscale for the second simulation free-flight scenario compared to the managed-flight scenario. On the other hand, pilots' supply of attention resources can be expected to increase with free flight introduction [$F(2, 28) = 5.40$; $p < .10$; $\varepsilon^2 = .28$]. Concerning the demand of attention resources, controllers made significantly lower ratings for the free flight conditions compared to the managed flight condition [within-subjects contrasts to managed flight condition: Free Flight Condition 1. Run $F(1, 4) = 5.08$; $p < .10$; $\varepsilon^2 = .56$; Free Flight Condition 2. Run $F(1, 4) = 9.65$; $p < .10$; $\varepsilon^2 = .71$]. Pilots' ratings indicate a substantial increase in demand on attention resources with introducing free flight. However, only between the second scenario run of the free flight condition and the managed flight conditions can a difference in ratings be observed [within-subjects contrast: $F(1, 14) = 25.11$, $p < .10$, $\varepsilon^2 = .64$]. This decrease of controllers' and increase of pilots' attention demand with the introduction of free flight is mirrored by the NASA TLX ratings. The experimental conditions have a significant effect on controllers' experienced task load [$F(2, 8) = 6.38$, $p < .10$, $\varepsilon^2 = .62$], with the highest mean ratings for the managed flight condition and the lowest mean ratings for the second simulation run of the free flight condition. For pilots otherwise the introduction of free flight is accompanied by an increase of experienced task load, especially when comparing the second simulation run of the free-flight scenario with the managed flight condition [within-subject contrasts: $F(1, 14) = 9.83$, $p < .10$, $\varepsilon^2 = .41$]. When NASA TLX subscales come under closer scrutiny, data give indication that workload experience of pilots is mainly attributable to a strong increase of mental demand. ISA data provide an insight into the gradient of situation awareness and workload during a simulation run. There is an indication in ISA ratings, that introducing free flight causes an increase of situation awareness (pilots) and workload experience (ATCOs) (see Table 1 and Table 2). However, effects are of small size ($\varepsilon^2 < .40$) so these should not be interpreted as sufficient evidence. For controllers there are significantly lower scores on situation awareness during the crossing situation of the managed-flight scenario compared to the corresponding ratings of the first [$F(1, 4) = 10.29$, $p < .10$, $\varepsilon^2 = .72$] and second [$F(1, 4) = 42.67$, $p < .10$, $\varepsilon^2 = .91$] free flight runs (see Table 1). Accordingly there are significantly higher workload scores for the crossing situation in the managed-flight scenario compared to the ratings for the first [$F(1, 4) = 10.00$, $p < .10$, $\varepsilon^2 = .71$] and second [$F(1, 4) = 36.00$, $p < .10$, $\varepsilon^2 = .90$] free flight run, respectively (see Table 2). Concerning the preceding merging situation, rating scores provide a trend that controllers' situation awareness is higher in the second free flight run compared to the managed flight run [$F(1, 4) = 4.57$, $p < .10$, $\varepsilon^2 = .53$].

Comparing operator positions concerning situation awareness and workload. There is distinctive evidence on all measures used (see Table 2) that under the managed flight condition workload for controllers is significantly higher and situation awareness significantly lower than for pilots [$F(8, 11) = 16.29$, $p < .10$, $\varepsilon^2 = .92$]. However, under free flight conditions the picture changes. For the first run of the free-flight scenario the overall difference between operator positions concerning their ratings is insignificant. Single comparisons just reveal a relevant difference in ISA ratings concerning situation awareness [$F(1, 18) = 4.65$, $p < .10$, $\varepsilon^2 = .43$] (see Table 1). Referring to the second run there is no further indication that operators on board and on the ground have a different degree of situation awareness and workload. However, there is even weak evidence (small effect) that pilots in the second free-flight scenario experience a higher level of workload in the crossing situation than their counterparts on the ground [$F(1, 19) = 4.65$, $p < .10$, $\varepsilon^2 = .20$].

Table 2: Workload Rating Scores (Standard Errors in brackets)

Independent variables		NASA TLX	ISA (workload; range: 1-3) Merging	Crossing	Fanning
MAS	ATCOs	72.1 (8.2)	2.2 (.2)	2.6 (.2)	2.2 (.2)
	Pilots	26.4 (3.8)	1.3 (.1)	1.5 (.1)	1.5 (.2)
FFAS 1st Run	ATCOs	55.9 (11.2)	2.2 (.2)	1.6 (.4)	2.0 (.3)
	Pilots	35.0 (4.1)	1.7 (.1)	1.5 (.1)	1.7 (.2)
FFAS 2nd Run	ATCOs	49.7 (10.5)	2.0 (.3)	1.4 (.2)	1.8 (.2)
	Pilots	40.9 (4.8)	1.6 (.1)	1.9 (.1)	1.8 (.2)

Dependent variables: NASA TLX; ISA (workload; range: 1-3)

Correlation of measurements. The number of flight level instructions is positively related to the number of STCA (*r*= .94; p< .10). The cause underlying this correlation may be the requirements for reacting on separation warnings within a scenario run. Under the second run of the free-flight scenario the number of flight level instructions is also correlated to the number of STCA (*r*=.96; p< .10), with an additional relation to losses of separation (*r*=.89; p< .10). In this regard no correlation can be detected under the first run. This reflects that controllers in free flight are not forced to act when separation violations are signalised. However, when after the first free flight run they would have tried to work more proactively to avoid future separation violations within the free flight zone, the negative correlation does not indicate that this goal is achieved. The number of route directs shows a trend for a negative correlation to the number of STCA (*r*= -.84; p< .10). This may reflect that controllers more frequently gave route directs to the pilots in scenario runs with lower conflict potential. Again, this relation is only significant for the managed flight condition. There is a trend for a negative correlation between controllers' SART and NASA TLX ratings concerning both, the first (*r*= -.83; p< .10) and the second run (*r*= -.82; p< .10) of the free-flight scenarios. When controllers experienced high workload there is a high probability that this is paired with the experience of low situation awareness. Under the first run of the free-flight scenario no such relation is observable. In the first free flight simulation runs there is a trend for a positive correlation between controllers' ISA workload ratings in the merging situation and the total number of STCA (*r*= .84; p< .10), and Losses of Separation (*r*= .87; p< .10) respectively. As warnings for conflicts with synthetic aircraft are excluded from the analysis, this indicates that the highest probability for mutual separation violation of concurrently piloted aircraft occurred during the merging situation after entering the free flight zone, as is intended by the principles of scenario construction. Pilots' ratings reveal a consistent negative relation between workload and situation awareness experience in the cockpit. The negative relation between SART and NASA TLX scores is significant for pilot ratings in all three experimental conditions (managed flight: *r*= -.57; p< .10; free flight first run: *r*= -.68; p< .10; free flight second run: *r*= -.75; p< .10). In the second free flight run NASA TLX scores are marginally positive correlated with the number of times the aircraft concerned received instructions form ATC (*r*= -.51; p< .10). In the first run, the ISA workload ratings for the crossing situation as a trend are also correlated with the number of times the aircraft concerned received instructions form ATC (*r*= .49; p< .10). As workload ratings may also give an indication of the density of traffic situations the pilots are in, both trends may denote the controllers' view of urgency.*)*

Table 3: Relevant differences in F-JAS sub-scales (Range: 1-7) between ATCOs and pilots for all experimental conditions (standard errors in brackets)

	Simulation Scenarios					
	MAS		*FFAS 1st Run*		*FFAS 2nd Run*	
F-JAS Subscale	*ATCO*	*Pilot*	*ATCO*	*Pilot*	*ATCO*	*Pilot*
Originality	*4.9 (.9)*	*2.4 (.3)*				
Memorization	*5.6 (.4)*	*3.7 (.4)*	*5.4 (.2)*	*3.6 (.4)*	*5.6 (.4)*	*3.9 (.4)*
Problem sensitivity	*6.5 (.3)*	*4.1 (.5)*	*6.5 (.3)*	*4.7 (.4)*		
Mathematical reasoning	*4.4 (.2)*	*2.6 (.3)*			*4.8 (.4)*	*2.6 (.4)*
Number facility	*5.8 (.4)*	*2.8 (.4)*	*5.4 (.2)*	*3.6 (.4)*	*5.4 (.2)*	*3.7 (.4)*
Information ordering	*5.2 (.2)*	*3.9 (.2)*				
Category flexibility	*4.8 (.6)*	*3.2 (.3)*				
Speed of closure	*6.2 (.5)*	*3.6 (.3)*				
Flexibility of closure	*5.6 (.5)*	*3.5 (.3)*				
Visualization	*6.0 (.3)*	*4.6 (.3)*				
Perceptual speed					*5.8 (.5)*	*4.7 (.2)*
Selective attention	*5.8 (.6)*	*3.9 (.3)*	*6.0 (.4)*	*4.5 (.2)*	*6.2 (.4)*	*4.4 (.3)*
Timesharing	*6.6 (.3)*	*4.4 (.3)*				
Response orientation	*5.4 (.4)*	*3.7 (.4)*				
Reaction time	*6.0 (.3)*	*3.6 (.5)*				
Resilience	*5.8 (.4)*	*3.4 (.4)*	*5.6 (.5)*	*3.2 (.4)*		
Stress resistance	*6.2 (.4)*	*4.1 (.4)*				

	Simulation Scenarios					
	FFAS 1st Run		*FFAS 1st Run*		*FFAS 1st Run*	
F-JAS Subscale	*ATCO*	*ATCO*	*ATCO*	*ATCO*	*ATCO*	
Resistant. to premature judgment	*5.8 (.5)*	*4.1 (.4)*				
Decision making	*6.2 (.4)*	*4.4 (.5)*	*6.4 (.4)*	*4.9 (.4)*		
Reliance on machine					*6.0 (.4)*	*4.2 (.3)*

Fleishman Job Analysis Survey (F-JAS)

In this analysis, only effects of at least medium size ($\varepsilon^2 > .40$) are considered. In Table 3 it is obvious that the number of F-JAS rating dimensions that show relevant differences between ATCOs and pilots is distinctly lower under the free flight than under the managed flight conditions. This result clearly supports the hypothesis of the convergence of pilot's and air traffic controllers' expert ratings for the free flight condition. Relevant differences between the experimental conditions are measured on five (ATC), or six, respectively (Pilot) F-JAS scales out of 40. Significant differences between the operational positions (in at least one of the experimental conditions) are measured on 23 out of 40 scales. These are predominantly scales that measure cognitive abilities.

Comparing ratings made after the managed flight condition with those after the free flight conditions, controllers as well as pilots gave significantly different statements regarding the ability to come up with "unusual or clever ideas about a given situation" (*Originality*). Controllers' experience based ratings regarding required originality to perform the given tasks under free flight conditions show significantly lower values compared to ratings on the same subscale for the managed flight conditions [$F(2, 8) = 6.00$, $p < .10$, $\varepsilon^2 = .60$]. On the contrary, pilots rated the requirement for originality (Table 3) significantly higher for free-flight scenarios than for managed-flight scenario [$F(2, 26) = 18.01$, $p < .10$, $\varepsilon^2 = .58$]. Only under the managed flight condition is there a group effect [Mann-Whitney test, $U = 12.50$, $p = .03$], indicating that there is a higher originality requirement for controllers than for pilots. However, under the free flight conditions no corresponding group effect is observed, indicating a convergence of requirement profiles on this dimension.

For the second run of the free-flight scenario, pilots also rated higher requirements to "detect known patterns from a background" (*Flexibility of Closure*) compared to their corresponding ratings for the managed-flight scenario [$F(1, 13) = 10.11$, $p < .10$, $\varepsilon^2 = .44$]. Again, only under the managed flight condition there is a group effect [Mann-Whitney test, $U = 7.00$, $p = .01$], indicating that there is a higher requirement to detect known patterns from a background for controllers than for pilots. However, under the free flight conditions no such group effect is observed, indicating a convergence of requirement profiles also on this dimension. Additionally, ratings indicate a trend for lower requirements to the controllers' ability to listen and understand spoken words and sentences (*Oral Comprehension,* see Table 2) under free flight situations [$F(1, 4) = 4.33$, $p < .10$, $\varepsilon^2 = .52$]. On the sensory and perceptual level, only the ability of visual colour discrimination is rated comparably higher by pilots after performing the second simulation run of the free-flight scenario in using a CDTI [$F(1, 13) = 14.36$, $p < .10$, $\varepsilon^2 = .53$]. On the level of interactive abilities, pilots' ratings concerning situation awareness requirements significantly vary between the managed flight and the second free flight conditions [$F(1, 13) = 23.40$, $p < .10$, $\varepsilon^2 = .64$].

Discussion

The main goal of this study is to exemplarily identify shifts in the ability requirements for ATCOs and pilots related to the introduction of new ATM concepts, with the long term perspective to utilize these results for the adaptation of current recruitment systems. The question is raised what differences may emerge regarding work conditions by introducing new airborne separation procedures. It is hypothesized that future job functions are more interchangeable than today. At the same time the study explored whether an integrated simulation platform built by linking two off the shelf simulators (*Microsoft Flight Simulator* and *London Control*) provides a usable low cost alternative for validations of future operational concepts.

The study results give following evidence to the open questions. The performance increase of the JCS concerning safety in the second free-flight scenario is contingent to an increase of separation related instruction of the ATCOs from the first to the second free-flight scenario, as well as with a decrease in controllers' workload and an increase in their reported situation awareness. This can be interpreted as an indication that controllers may have learned from the first to the second run to use the spare mental capacity they have gained under free flight conditions to anticipate the traffic flow and take measures to proactively avoid conflicts emerging in the free flight sector. This hypothesis is congruent with the observation that instructions are given earlier in time during the second free flight run compared to the first run.

The increase in pilots' workload under free flight up to the level of the controllers gives first evidence that the requirements to the different actors may converge. When analyzing the sources of workload it becomes obvious that pilots experience a higher level of mental demand, a concept which is connoted to the general cognitive operations of thinking, deciding, mental arithmetic, remembering, and searching. Further information about the kind of changes in requirements is provided by the F-JAS scales. The experiences stated by the pilots to be more occupied with detecting known patterns from a background and visual color discrimination under free flight can be attributed to the use of the onboard ASAS (CDTI), which reflects basically a radar display. The ratings of pilots and controllers regarding these dimensions are similar under free flight conditions, because both are using radar displays for separation tasks.

However, the most sounding difference in experience of job requirements of ATCOs and pilots is assigned to the dimension of originality. Under free flight pilots experience a pronounced increase in requirements to come up with unusual or clever ideas about a given traffic situation. Their ratings and the controllers' ratings again are on a comparable level, because pilots under free flight are doing parts of the work the controller did before. But what has to be kept in mind is that pilots perform these similar tasks under the distinct conditions predefined by the cockpit workplace with its different (i.e., 'egocentric') perspective on the traffic situations to be controlled. For controllers under free flight experience no reduction in their job requirements regarding originality could be found because they are still (pro-)actively involved in traffic problem solving.

First of all, the data surveyed in this study reveal a tendency for a greater overlap of job functions on board and on the ground. This preliminary evidence shown for a self separation scenario supports the central hypothesis that in the coming ATM system ability requirement profiles for ATCOs and pilots will be more congruent or even identical (see Eißfeldt, 2009; Bruder, Jörn, & Eißfeldt, 2008). Secondly, it is shown that the exploitation of a low cost simulation can provide important data to better understand human factors issues in the context of investigating new operational concepts for the future ATM. Hollnagel's (2007) main conclusion that the two conditions of managed and free flight considerably differ regarding control demands, and hence regarding the required tasks is underpinned by the results of the current study. The question may be raised whether exocentric (ATCOs) vs. egocentric (pilots) view on traffic situation sets significantly different task requirements. An answer would clarify if examining the separation task in the cockpit is a case of studying different work under different conditions, or rather a case of studying the same work under different conditions.

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